

INTERLEAVER AND DEINTERLEAVER FOR USE IN A DIVERSITY TRANSMISSION COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

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CROSS REFERENCE

This application is a continuation application of co-pending Application Serial No. 09/293,527, filed April 15, 1999, entitled "Interleaver and Deinterleaver for Use in a Diversity Transmission Communication System."

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I. Field of the Invention

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The current invention relates to wireless telecommunications. More particularly, the present invention relates to a novel and improved transmitter design for enhancing the reliability and communications in a wireless communications system.

II. Description of the Related Art

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The use of code division multiple access (CDMA) modulation techniques is one of several techniques for facilitating communications in which a large number of system users are present. Other multiple access communication system techniques, such as time division multiple access (TDMA), frequency division multiple access (FDMA) and AM modulation schemes such as amplitude companded single sideband (ACSSB) are known in the art. However, the spread spectrum modulation technique of CDMA has significant advantages over these other modulation techniques for multiple access communication systems.

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The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS", assigned to the assignee of the present invention and incorporated by reference herein. The use of CDMA techniques in a multiple access communication system is further disclosed in

U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM", and in U.S. Patent No. 5,751,761, entitled "SYSTEM AND METHOD FOR ORTHOGONAL SPREAD SPECTRUM SEQUENCE GENERATION IN VARIABLE DATA RATE SYSTEMS", both assigned to the assignee of the present invention and incorporated by reference herein. The use of CDMA searchers is disclosed in U.S. Patent No. 5,764,687, entitled "MOBILE DEMODULATOR ARCHITECTURE FOR A SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM", assigned to the assignee of the present invention and incorporated by reference herein. Code division multiple access communications systems have been standardized in the United States in Telecommunications Industry Association TIA/EIA/IS-95-A, entitled "MOBILE STATION-BASE STATION COMPATIBILITY STANDARD FOR DUAL-MODE WIDEBAND SPREAD SPECTRUM CELLULAR SYSTEM", hereafter referred to as IS-95 and incorporated by reference herein.

The CDMA waveform, by its inherent nature of being a wideband signal, offers a form of frequency diversity by spreading the signal energy over a wide bandwidth. Therefore, frequency selective fading affects only a small part of the CDMA signal bandwidth. Space or path diversity on the forward or reverse link is obtained by providing multiple signal paths through simultaneous links to or from a mobile user through two or more antennas, cell sectors or cell-sites. Furthermore, path diversity may be obtained by exploiting the multipath environment through spread spectrum processing by allowing a signal arriving with different propagation delays to be received and processed separately. Examples of the utilization of path diversity are illustrated in U.S. Patent No. 5,101,501 entitled "SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM", and U.S. Patent No. 5,109,390 entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM", both assigned to the assignee of the present invention and incorporated by reference herein.

In the CDMA demodulator structure used in some IS-95 systems, the PN chip interval defines the minimum separation two paths must have in order to be combined. Before the distinct paths can be demodulated, the relative arrival times (or offsets) of the paths in the received signal must first be determined. The demodulator performs this function by "searching" through a sequence of offsets and measuring the energy received at each offset. If the

energy associated with a potential offset exceeds a certain threshold, a demodulation element, or "finger" may be assigned to that offset. The signal present at that path offset can then be summed with the contributions of other fingers at their respective offsets.

5 A method and apparatus of finger assignment based on searcher and finger energy levels is disclosed in U.S. Patent No. 5,490,165, entitled "FINGER ASSIGNMENT IN A SYSTEM CAPABLE OF RECEIVING MULTIPLE SIGNALS", assigned to the assignee of the present invention and incorporated by reference herein. In the exemplary embodiment, the CDMA
10 signals are transmitted in accordance with IS-95. An exemplary embodiment of the circuitry capable of demodulating IS-95 forward link signals is described in detail in U.S. Patent No. 5,764,687, entitled "MOBILE DEMODULATOR ARCHITECTURE FOR A SPREAD SPECTRUM MULTIPLE ACCESS SYSTEM", assigned to the assignee of the present invention and incorporated
15 by reference herein. An exemplary embodiment of the circuitry capable of demodulating IS-95 reverse link signals is described in detail in U.S. Patent No. 5,654,979, entitled "CELL SITE DEMODULATOR ARCHITECTURE FOR A SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM," assigned to the assignee of the present invention and incorporated by
20 reference herein.

In the exemplary embodiment, the signals are complex PN spread as described in U.S. Patent Application Serial No. 08/856,428, entitled "REDUCED PEAK TO AVERAGE TRANSMIT POWER HIGH DATA RATE IN A CDMA WIRELESS COMMUNICATION SYSTEM," filed April 9, 1996, assigned to the
25 assignee of the present invention and incorporated by reference herein, and in accordance with the following equations:

$$I = I' PN_I + Q' PN_Q \quad (4)$$

$$Q = I' PN_Q - Q' PN_I \quad (5)$$

30 where PN_I and PN_Q are distinct PN spreading codes and I' and Q' are two channels being spread at the transmitter.

The International Telecommunications Union recently requested the submission of proposed methods for providing high rate data and high-quality
35 speech services over wireless communication channels. A first of these

proposals was issued by the Telecommunications Industry Association, entitled "The cdma2000 ITU-R RTT Candidate Submission". A second of these proposals was issued by the European Telecommunications Standards Institute (ETSI), entitled "The ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT
5 Candidate Submission". And a third proposal was submitted by U.S. TG 8/1 entitled "The UWC-136 Candidate Submission" (referred to herein as EDGE). The contents of these submissions is public record and is well known in the art.

In addition to the aforementioned properties, CDMA's broadband nature permits the demodulation of signals having traversed different propagation
10 paths. In U.S. Patent Nos. 5,280,472, 5,513,176, 5,553,011, assigned to the assignee of the present invention and incorporated by reference herein, the usage of multiple sets of distributed antennas is employed to deliberately provide multiple paths of propagation. In the just mentioned U.S. Patents, sets of antennas are fed by a common signal with only time delay processing to
15 distinguish signals. The transmit output of the base station is fed to a string of antenna elements for example with a coaxial cable. The antenna elements connect to the cable using power splitters. The resulting signals, amplified and frequency converted as necessary, are fed to the antennas. The salient features of this distributed antenna concept are as follows: (1) simple and
20 inexpensive dual antenna node design; (2) neighboring antennas have time delays inserted in feed structure so signals received and transmitted from neighboring antennas are distinguishable by PN temporal processing; (3) exploitation of direct sequence CDMA's ability to discriminate against multipath; and (4) creation of deliberate multipath that satisfies discrimination criteria.

25 Antenna transmit diversity as well as multi-carrier transmission are promising new technologies that improve transmission resistance to fading by offering space and/or frequency diversity. In the antenna transmit diversity case for example, the data to be transmitted is encoded into symbols, which are then distributed among the antennas and transmitted.

30 Many techniques have been proposed for mitigating mutual interference between signals transmitted from the different antennas. Such techniques include delay transmit diversity, orthogonal transmit diversity (OTD), time switched transmit diversity (TSTD), time delayed transmit diversity (TDTD), and multi-carrier transmit diversity (MCTD). Each of these methods shares with the
35 others a common goal of providing additional diversity in the transmitted signal

through space, time, frequency or code space. Copending U.S. Patent No. 6,215,777, entitled "Method and Apparatus for Transmitting and Receiving Data Multiplexed onto Multiple Code Channels, Frequencies and Base Stations", filed September 15, 1997, assigned to the assignee of the present invention and incorporated by reference herein, describes a matrix of methods for transmitting CDMA signals using multiple carriers and multiple code channels for introducing diversity into the transmitted signal. These methods are known in the art and have been described in proposals to the International Telecommunications Union in response to their request for proposed Third Generation Wireless communication systems. Methods for introducing diversity into a transmitted signal are almost limitless by their very nature.

In addition, the multi-carrier transmission, whether it uses antenna transmit diversity or not, must distribute the coded symbols among the different carriers, which is similar to distributing symbols among several antennas in an antenna transmit diversity system. One skilled in the art will appreciate that, in the case where a multi-carrier system uses a single transmit antenna, the channels utilizing the two carriers may still be thought of as independent transmission channels which may or may not suffer from correlated fading.

In a system utilizing interleaving in conjunction with transmit diversity, it is desirable to fully utilize the gain offered by both techniques, as well as to make sure that the interleaver also performs well when the transmission channels become correlated. For example, in a system utilizing two transmission channels, using either two transmit antennas or two carriers, correlated fading in both transmission channels may cause the loss of adjacent transmitted coded symbols. Decoders such as trellis decoders and turbo decoders are often more susceptible to the loss of several successive symbols than to the loss of the same number of symbols spread throughout the data stream. In order to reduce the probability of loss of adjacent encoded symbols, interleavers such as block interleavers and turbo coded interleavers are employed. However, these traditional interleaving methods provide less time diversity when employed by traditional means in systems employing transmission diversity. Thus, there is a need felt in the art for a method of decreasing the chances of losing successive symbols in a system which utilizes transmit diversity.

SUMMARY OF THE INVENTION

The current invention enhances the performance of a system utilizing interleaving and transmit diversity by reordering the sequence of symbols transmitted along the different transmission channels. For example, in the case of a system using two transmission channels, the symbols being transmitted on one channel are shuffled with respect to the symbols transmitted through the other channel. This shuffling makes it less likely that successive symbols output by the interleaver are lost to correlated fading in the two transmission channels.

Suppose we have a source frame F composed of N coded symbols S_i ($1 < i < N$). Suppose also that we have to distribute these symbols S_i over M transmitters (different carriers or antennas or both). The current invention splits the symbols into M groups G_j ($1 < j < M$), one for each transmitter. Then each of the groups G_j is interleaved independently.

A problem which can occur if the interleavers and splitter are not chosen correctly, or even worse if they are all identical, is that the performance will be severely degraded when the signals from the different transmitters go through channels that are correlated.

Typically there are 2 transmitters that lead to 2 antennas, and the splitter simply consists of a demux operation that send odd symbols to G_1 and even symbols to G_2 , in which the interleavers for G_1 and G_2 typically use identical interleaving methods. If there is no shuffle, then the system's performance will be severely degraded when the fading on the paths from antenna 1 and 2 are correlated.

The goal of the shuffle is to make sure that even if the different transmission paths from the different transmitters become correlated, the performance degradation is minor. One particularly efficient implementation of the shuffle that each shuffle cyclically rotates the symbols it receives. Here is an example:

Shuffler j : cyclically rotate the symbols to be transmitted by transmitter j by $(j-1) \cdot N/M$ symbols. Thus, if $N = 4$, $M = 2$ and G_2 after interleaving is "abcd", then shuffler 2 would output "cdab", which is "abcd" that has been cyclically

rotated by $N/M=2$ symbols. An alternative embodiment of a shuffler is a flip. This transforms "abcd" into "dcba".

It will be understood by one skilled in the art that the shuffle operations, though presented as being subsequent to and separate from the traditional interleaving operation, in reality would probably be combined with interleaving, yielding a single operation in a real implementation.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is a diagram illustrating basic components of a wireless communication system incorporating an embodiment of the invention.

FIG. 2 is a block diagram of a preferred embodiment of the invention in a wireless base station.

FIG. 3 is a block diagram of a preferred embodiment of the invention in a wireless subscriber station.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 shows the present invention in the context of a wireless communication system. The base station transceiver subsystem (BTS) 2 includes two transmit antennas 4 and 6, which are used to transmit signals along two transmission channels 8 and 10 to a subscriber station 12. The present invention is applicable to any communication system employing diversity transmission. In the exemplary embodiment, the signals transmitted from base station transceiver subsystem (BTS) 2 are code division multiple access communication signals. One skilled in the art will appreciate that the BTS could be replaced by a wireless local loop concentrated subscriber station (CSS) or any other transmitter employing diversity transmission without departing from the embodied invention. The generation and transmission of code division multiple access communication signals is well known in the art

and is described in detail in the aforementioned U.S. Patent No. 5,103,459 and in the IS-95 specification. The present invention is also applicable to frequency division multiple access (FDMA) communication systems and to time division multiple access (TDMA) communication systems, such the GSM communication system and the proposed third generation TDMA communication system commonly referred to as EDGE.

The transmit antennas **4** and **6**, could be separated spatially to provide transmit diversity by either placing them in different physical locations, or by using directional antennas pointed in different directions from each other. In an alternate embodiment using multicarrier transmit diversity, the two antennas **4** and **6** could be the same physical transmit antenna.

The subscriber station **12** is shown as a car, but could also be a wireless modem, wireless local loop subscriber station, or any other portable wireless communication subscriber equipment. The method and apparatus for simultaneously receiving multiple transmissions is well known in the art. In the exemplary embodiment, the signals transmitted from antennas **4** and **6** are received at subscriber station **12** using a RAKE receiver, the implementation of which is well known in the art and is described in the aforementioned U.S. Patent No. 5,109,390.

FIG. 2 shows a preferred embodiment of the invention as used in a wireless base station (BTS). Data to be transmitted to the subscriber station is input first to a frame formatter **100**. The data which is encapsulated in the frame formatter may be voice data, fax, packet data, or any other data capable of being represented by a digital bit stream.

The frame formatter **100** is operationally coupled with a forward error correction (FEC) module **102**, which adds forward error correction codes to the data stream. The FEC module **102** may use any of several forward error correction techniques, including turbo-coding, convolutional coding, or other form of soft decision or block coding.

After FEC coding, the data is processed by a demultiplexor, or demux **104**, which is operationally connected to the FEC module **102**. Demux **104** distributes the error correction coded symbols into different groups, each of which is processed separately until transmission. Though **FIG. 2** depicts the use of two groups, one skilled in the art will appreciate that demux **104** may

distribute symbols into more than two groups without departing from the embodied invention. In the exemplary embodiment, the method of demultiplexing the single symbol stream into two symbol streams includes simple alternation, in which all odd symbols are distributed into one, and all even symbols are distributed into the other.

Each group of bits is then processed by an interleaver **106** and **108**, operably connected to the demux **104**. Each interleaver may utilize any of a number of interleaving techniques, such as block interleaving and bit reversal interleaving.

The output of one interleaver **106** is sent to a transmit subsystem **126**, shown in the exemplary embodiment as including a Walsh spreader **112**, a PN spreader **116**, and a transmitter **122**. The output of interleaver **106** is sent to the Walsh spreader **112**, which is operably connected to the interleaver **106**.

CDMA systems that include an orthogonal spreading followed by a PN spreading are described in detail in the aforementioned U.S. Patent No. 5,109,459. It will be understood that, although described in the context of traditional Walsh codes, the present invention is applicable to other orthogonal channelization methods such as orthogonal variable length spreading functions of the proposed WCDMA standard and described in detail the aforementioned U.S. Patent No. 5,751,761. In the exemplary embodiment, the PN spreading can be performed using either a traditional quadrature PN spreading such as standardized in the IS-95 standard or using a complex PN spreading such as described in the proposed cdma2000 and WCDMA Third Generation standards and described in detail in the aforementioned copending U.S. Patent Application Serial No. 08/856,428.

In a CDMA system using orthogonal Walsh coding, the channels that are distinguished from each other by utilizing these Walsh codes are referred to as Walsh channels. One skilled in the art will appreciate that a system could include transmission subsystems using an alternate form of signal separation technique, such as FDMA or TDMA, without departing from the embodied invention.

As shown, the unshuffled output of the first interleaver **106** is processed in a manner typical of many current CDMA systems. The signal proceeds to a Walsh spreader **112**, which is operably connected to the interleaver **106**, and

then to a PN spreader **116**, which is operably connected to the Walsh spreader **112**. The Walsh spreader **112** serves to multiply each data bit coming from the interleaver **106** by a Walsh code W_i , while the PN spreader provides superior autocorrelation properties that allows for the demodulation of multipath signals.

- 5 The PN spread signal from PN spreader **116** is provided to transmitter **122** which amplifies, upconverts and filters the signal from transmission through antenna **4** on transmission channel **8**.

The output of the second interleaver **108** is sent to a shuffler **110**, operationally connected to the interleaver **108**, which resequences the data output by the interleaver **108**. The output of the shuffler **110** is then sent to a second transmission subsystem **128**, again shown in an exemplary embodiment as including a Walsh spreader **114**, a PN spreader **118**, and a transmitter **124**. The output of the shuffler **110** is sent to the Walsh spreader **114**, which is operably connected to the shuffler **110**. The Walsh spreader **114** serves to multiply each data bit coming from the shuffler **110** by a Walsh code W_j .

In a preferred embodiment of the invention, the shuffler **110** operates by cyclically rotating each group of four sequential symbols *abcd* into a different sequence of bits *cdab*. Other shuffling functions, such as reversing or flipping, may be used without departing from the embodied invention. One skilled in the art will appreciate that additional shuffling functions may be utilized for each symbol group, in a system having more than two such groups. The goal of the shuffling process is to reduce the effects of correlated fading on transmission channels **8** and **10**. By employing shuffler **110**, a fade simultaneously effecting transmission channels **8** and **10** will not erase consecutive symbols in the frame of symbols. As is well known in the art, forward error correction decoders such as trellis decoders and turbo decoders are much more effective in correcting errors that not consecutive than they are at correcting those that are.

The output of the shuffler **110** is processed in much the same way as the unshuffled signal from the first interleaver **106**. The shuffled signal proceeds from the shuffler **110** to a Walsh spreader **114**, and then to a PN spreader **118**.

In an alternative embodiment of the invention using multiple carriers to accomplish transmit diversity, both transmission subsystems **126** and **128** may share a single transmit antenna.

The exemplary embodiment envisions three alternative methods of separation of the signals transmitted from antennas **4** and **6**. In the first embodiment, the signals transmitted from antennas **4** and **6** are transmitted on the same frequency and the separation of the signals is provided by spreading the signals prior to transmission using different Walsh functions. In the second exemplary embodiment, the signals transmitted from antennas **4** and **6** are transmitted on different carrier frequencies in which case the Walsh spreading operations performed by Walsh spreaders **112** and **114** may be either the same or different. In an alternative embodiment, the signals are distinguished from one another by introducing a delay prior to transmission using delay element **120**. Methods of time transmit diversity are described in detail in aforementioned U.S. Patent Nos. 5,280,472, 5,513,176 and 5,533,011. In this alternative embodiment, the signals transmitted from antennas **4** and **6** are on the same frequency and may or may not be spread using the same Walsh spreading function in Walsh Spreaders **112** and **114**.

FIG. 3 shows a preferred embodiment of the invention as used in a CDMA wireless subscriber station. The signal is received through antenna **200** and processed by receiver **202**. The resultant signals are then processed by multiple demodulation subsystems **207** and **209**. Demodulation subsystem **207** demodulates the signal that has traversed transmission channel **8**. Deinterleaver **216** receives the demodulated signal output by the demodulation subsystem **207** and de-interleaves the signal.

If the signal that has traversed transmission channel **8** is transmitted on the same frequency as the signal transmitted on transmission channel **10**, then receiver **202** amplifies, down converts and filters the signal using the same hardware. However, if the signals that traversed transmission channels **8** and **10** have been transmitted on different carrier frequencies, then the received signal will be downconverted using different mixing frequencies and the resultant signals from the different mixing operation will be provided to demodulation subsystem **207** and **209**.

Demodulation subsystem **209** demodulates the signal that has traversed transmission channel **10**. Within demodulator **207**, PN demodulator **206** demodulates the received signal in accordance with a PN offset that is determined in accordance with a signal from searcher **204**. The

implementation of CDMA searchers is well known in the art, an exemplary embodiment of which is described in detail in aforementioned U.S. Patent No. 5,764,687.

5 The PN despread signal is provided to Walsh despreader, which removes the Walsh covering from the PN despread signal. The signal produced by the demodulator subsystem **207** is provided to de-interleaver **216**, which de-interleaves the uncovered signal so as to undo the interleaving operation performed by interleaver **106**.

10 The signal which traversed transmission channel **10** is demodulated in demodulation subsystem **209**, within which the received signal is processed using a PN demodulator **208**, and then despread using a Walsh despreader **212**. The output of the demodulation subsystem **209** is then processed by an operably connected deshuffler **214**. The deshuffler **214** performs the inverse function of the shuffler **110**. The deshuffled output of the deshuffler **214** is then
15 sent to an operably connected deinterleaver **218**. The deinterleaver **218** performs the inverse function of the interleaver **108**.

The output of the interleavers **216** and **218** are connected to a multiplexor or MUX **220**, which performs the reverse operation of the demux **104** to form a single data stream. The resulting single data stream is then
20 processed by a FEC decoder **222**, which performs error correction according to the forward error correction code utilized by the FEC coder **102**. As with the FEC coder, the FEC decoder may use any of several forward error correction techniques, including turbo-coding, convolutional coding, or other form of soft decision or block coding.

25 The data output by the FEC decoder **222** is then processed by a frame checker **224**, which verifies the validity of the received frames, usually using a CRC.